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MCG DISTANCE-BASED TRAINING - APPLICATION NOTE#1

VOLTAGE AND BLDC MOTORS

One of the most basic parameters of a brushless dc motor is voltage but this might possibly be one of the least understood. In generic terms voltage is **electromotive force** or **electrical pressure** and is defined as **the electrical potential energy per unit charge.** At this point you might think - "huh, that's nice" - and be tempted to file this note in your "circular file." Don't do that just yet. We aren't going to get into a great deal of theory or technical jargon in this or in future application notes but rather attempt to provide basic information to help you field application questions for our products. I suspect these application notes will never find their way into industry journals or white papers but I do hope they will provide simple technical answers to real world questions. Here is a common question we see very often regarding a brushless motor:

"The customer has looked through the catalog and wants a BN28-29AF motor but needs it to operate at 12 volts. Do you have a 12 volt motor?"

Good question. Let's see if we can provide a good answer back to the customer.

Some simple rules about motors and applied voltage are as follows:

- **The higher the applied voltage for a motor with a given back EMF constant (KE), the faster the motor will run.**
- **Conversely the lower the applied voltage for a motor with a given back EMP constant (KE), the slower the motor will run.**
- **The back EMF constant (KE - units in volts/krpm) is a measure of how many volts per 1000 rpm the motor would produce if driven as a generator. As a matter of fact KE is also called generator voltage.**
- **The KE can also be used to determine how fast a motor will run with a certain voltage applied to it. We will examine a simple formula we can use to calculate motor speed based upon back EMF.**
- **KEY POINT: The voltages listed in the catalog are representative of common voltages but are no means the only voltages available.**
- **KEY POINT: A motor rated at 24 volts will run at 12 volts or even at 36 volts (being careful to avoid exceeding mechanical or power limits of course).**
- **KEY POINT: Voltage as a lone parameter is useless. When a customer asks if we have a "12 volt motor" this is an incomplete question. If the customer asks if we "have a 12 volt motor that will run at 3000 rpm and 20 oz.-in. of torque" then we can help the customer.**

In our motor catalog we have performance tables that list the various performance parameters for a particular motor. For this example we will use the **BN28-29AF-01LH** - table below:

Part Number*		BN28-21AF-□□			BN28-29AF-□□			BN28-36AF-□□			BN28-44AF-□□		
Winding Code**		01	02	03	01	02	03	01	02	03	01	02	03
L = Length	inches	2.10			2.90			3.60			4.40		
	millimeters	53.3			73.7			91.4			111.8		
Terminal Voltage	volts DC	24.0	48.0	72.0	24.0	48.0	72.0	24.0	48.0	72.0	24.0	48.0	72.0
Peak Torque	oz-in	188.0	188.0	188.0	407.0	407.0	407.0	596.0	596.0	596.0	737.0	737.0	737.0
	Nm	1.3276	1.3276	1.3276	2.8740	2.8740	2.8740	4.2087	4.2087	4.2087	5.2043	5.2043	5.2043
Continuous Stall Torque	oz-in	43.0	44.0	46.0	71.0	74.0	72.0	93.0	95.0	93.0	106.0	108.0	105.0
	Nm	0.3036	0.3107	0.3248	0.5014	0.5226	0.5084	0.6567	0.6708	0.6567	0.7485	0.7626	0.7415
Rated Speed	RPM	9170	9230	9240	8870	8900	7890	5890	5910	5230	4660	4680	4120
	rad/sec	960	967	968	929	932	826	617	619	548	488	490	431
Rated Torque	oz-in	31	31	33	40	40	46	68	70	72	84	84	86
	Nm	0.2189	0.2189	0.2330	0.2825	0.2825	0.3248	0.4802	0.4943	0.5084	0.5932	0.5932	0.6073
Rated Current	Amps	10.26	5.13	3.63	12.67	6.33	4.29	14.31	7.35	4.51	14.25	7.13	4.35
Rated Power	watts	210.3	211.6	225.5	262.4	263.3	268.4	296.2	308.0	278.5	289.5	290.8	262.1
Torque Sensitivity	oz-in/amp	3.24	6.49	9.73	3.48	6.95	11.59	5.07	10.13	16.89	6.25	12.50	20.84
	Nm/amp	0.0229	0.0458	0.0687	0.0246	0.0491	0.0818	0.0358	0.0715	0.1193	0.0441	0.0883	0.1472
Back EMF	volts/KRPM	2.40	4.80	7.20	2.57	5.14	8.57	3.75	7.49	12.49	4.62	9.24	15.41
	volts/rad/sec	0.0229	0.0458	0.0687	0.0246	0.0491	0.0818	0.0358	0.0715	0.1193	0.0441	0.0883	0.1472
Terminal Resistance	ohms	0.14	0.51	1.08	0.07	0.25	0.72	0.10	0.38	1.05	0.12	0.47	1.38
Terminal Inductance	mH	0.18	0.72	1.62	0.11	0.43	1.19	0.17	0.69	1.92	0.24	0.97	2.69
Motor Constant	oz-in/sq.rt.watt	8.72	9.06	9.38	13.44	13.93	13.69	16.45	16.86	16.49	17.82	18.18	17.73
	Nm/sq.rt.watt	0.062	0.064	0.066	0.095	0.098	0.097	0.116	0.119	0.11645	0.12584	0.12835	0.12518
Rotor Inertia	oz-in-sec²x10⁻³	2.30	2.30	2.30	4.40	4.40	4.40	6.60	6.60	6.60	8.80	8.80	8.80
	g-cm²	162.3	162.3	162.3	310.5	310.5	310.5	465.8	465.8	465.8	621.0	621.0	621.0
Weight	oz	23.0	23.0	23.0	35.0	35.0	35.0	48.0	48.0	48.0	61.0	61.0	61.0
	g	653.2	653.2	653.2	994.0	994.0	994.0	1363.2	1363.2	1363.2	1732.4	1732.4	1732.4
# of Poles		8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Timing		120°	120°	120°	120°	120°	120°	120°	120°	120°	120°	120°	120°
Mech. Time Constant	ms	4.3	4.0	3.7	3.4	3.2	3.3	3.5	3.3	3.4	3.9	3.8	4.0
Electrical Time Constant	ms	1.30	1.40	1.51	1.64	1.73	1.66	1.79	1.91	1.83	1.95	2.05	1.95
Thermal Resistivity	deg. C/watt	2.9	3.0	2.9	2.5	2.6	2.6	2.2	2.2	2.3	2.0	2.0	2.1
Speed/Torque Gradient	rpm/oz-in	17.7	16.5	15.4	7.5	7.0	7.2	5.0	4.8	5.0	4.3	4.1	4.3

This table may be hard to read so feel free to look in the motor catalog or on the website - www.polysci.com. In looking at the **BN28-29AF-01LH** we see that its rated voltage is **24 VDC**. Taken by itself this is a pretty useless parameter. However combined with other parameters in the table we see that:

- At **24 VDC** and with a **rated torque load of 40 oz.-in**. applied to the motor, the motor will be running at approx. **8870 rpm.**
- We can calculate No-Load Speed by the following equation (simple equation that ignores friction but will get us within about 5%):

No-Load Speed = Voltage/KE x 1000

- From the data given on this motor:
  - **KE = 2.57 v/krpm**

  We can calculate the no-load speed of the motor at the rated 24 VDC - No-Load Speed @ 24 VDC = 24 Volts/2.57 v/krpm x 1000 = approx. **9338 rpm.**

Will the motor run at 12 VDC? Yes. We can again calculate no-load speed - No-Load Speed @ 12 VDC = 12 Volts/2.57 v/krpm x 1000 = approx. **4669 rpm.**

- As you can see by our calculations, **cutting the voltage in half cuts the speed in half.** While this is useful information - the customer now knows the motor will operate at 12 VDC - the real question is **Will the motor deliver the required speed and torque at 12 VDC?** There is a fairly simple equation we can use to determine this. Let's work an example:

Example:

Customer has selected a BN28-29AF-01LH but wants to operate it at 12 VDC. They need **5000 rpm** and **35 oz.-in.** at **12 VDC.** Will this motor do the job? Time for another equation:

Voltage Required at Motor = ((TL + TM)/KT x (RT)) + (KE x ω) - where:

TL = load torque
TM = friction torque of motor
KT = motor KT
KE = motor KE
RT = motor RT
ω = desired motor speed (in krpm)

The BN28-29AF-01LH has the following characteristics:

KT = 3.48 oz.-in./amp
KE = 2.57 v/krpm
RT = 0.07 ohms
Friction Torque - not a parameter we typically list but for this example assume 2.0 oz.-in.

Let's run the numbers:

Voltage required = ((35+2)/3.48 x (0.07)) + (2.57 x 5) = ***13.6 volts***

This motor will not meet the customer's performance parameters at 12 VDC. It will require 13.6 VDC in order to meet the load point. Let's do one more example:

Example:

Customer has selected a BN28-29AF-01LH but wants to operate it at 12 VDC. They need **4000 rpm** and **25 oz.-in.** at **12 VDC.** Will this motor do the job? Time for another equation:

Voltage Required at Motor = ((TL + TM)/KT x (RT)) + (KE x ω) - where:

TL = load torque
TM = friction torque of motor
KT = motor KT

KE = motor KE
RT = motor RT
ω = desired motor speed (in krpm)

The BN28-29AF-01LH has the following characteristics:

KT = 3.48 oz.-in./amp
KE = 2.57 v/krpm
RT = 0.07 ohms
Friction Torque - not a parameter we typically list but for this example assume 2.0 oz.-in.

Let's run the numbers:

Voltage required = ((25+2)/3.48 x (0.07)) + (2.57 x 4) = ***10.8 volts***

The motor will deliver the required performance at 12 VDC.

Hopefully this has been a useful application note. Again the primary points to remember are:

- **The higher the applied voltage for a motor with a given back EMF constant (KE), the faster the motor will run.**
- **Conversely the lower the applied voltage for a motor with a given back EMP constant (KE), the slower the motor will run.**
- **The back EMF constant (KE - units in volts/krpm) is a measure of how many volts per 1000 rpm the motor would produce if driven as a generator. As a matter of fact KE is also called generator voltage.**
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More to come….

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